PATENT

Attorney Docket No. IMRAA.015C1
Date: February 16, 2001
Page 1

COPY

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WASHINGTON, D.C. 20231

ATTENTION: BOX PATENT APPLICATION

Sir:

Transmitted herewith for filing is the patent application of

Inventor(s): **Martin E. Fermann**

For: **MODE-LOCKED MULTIMODE FIBER LASER PULSE SOURCE**

Enclosed are:

(X) 11 sheet(s) of drawing.

(X) This application is a continuation of prior application no. 09/199,728, filed November 25, 1998.

(X) A copy of Declaration from prior application is enclosed.

(X) Preliminary Amendment is enclosed.

(X) Incorporation by Reference. The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

(X) Return prepaid postcard.

CLAIMS AS FILED

FOR	**NUMBER FILED**	**NUMBER EXTRA**	**RATE**	**FEE**
Basic Fee			$710	$710
Total Claims	54 - 20 =	34 ×	$18	$612
Independent Claims	3 - 3 =	0 ×	$80	$0
TOTAL FILING FEE	$1322			

(X) A check in the amount of $1322 to cover the filing fee is enclosed.

(X) The Commissioner is hereby authorized to charge any additional fees which may be required, now or in the future,or credit any overpayment to Account No. 11-1410. A duplicate copy of this sheet is enclosed.

(X) Please use Customer No. 20,995 for the correspondence address.

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IMRAA.015A
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UNITED STATES DEPARTMENT OF COMMERCE
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Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR		ATTORNEY DOCKET NO.
09/199,728	11/25/98	FERMANN	M	IMRAA.015A

Jc978 U.S. PTO 09/785944 02/16/01

020995 MMC2/1122
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EXAMINER	
FLORES RUIZ, D	
ART UNIT	PAPER NUMBER
2877	

DATE MAILED: 11/22/00

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks

DOCKETED ON: DEC 08 2000
BY: ... VERIFIED BY: ...
ACTION: Amendment Due
DUE DATE: Feb. 22, 2001
FINAL DEADLINE: May 22, 2001
ATTY: JBB
ATTORNEY VERIFICATION OF DUE DATE AND FINAL DEADLINE: ____

KNOBBE MARTENS OLSON & BEAR
DEC 01 2000
RECEIVED

PTO-90C (Rev. 2/95)

2 - Mail Copy

Office Action Summary	Applicati n No.	Applicant(s)	
	09/199,728	FERMANN, MARTIN E.	
	Examiner	Art Unit	
	Delma R. Flores Ruiz	2877	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Peri d f r Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136 (a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).

Status

1)☒ Responsive to communication(s) filed on *November 15, 2000* .

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disp sition of Claims

4)☒ Claim(s) *1-58* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☒ Claim(s) *51 - 57* is/are allowed.

6)☒ Claim(s) *1 – 4, 7 – 19, 22 – 38, 40 – 42, 46 – 50 and 58* is/are rejected.

7)☒ Claim(s) *5 – 6, 20 – 21, 39, and 43 - 45* is/are objected to.

8)☐ Claims _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on *November 15, 2000* is/are objected to by the Examiner.

11)☐ The proposed drawing correction filed on _____ is: a)☐ approved b)☐ disapproved.

12)☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119

13)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

a)☐ All b)☐ Some * c)☐ None of the CERTIFIED copies of the priority documents have been:

1.☐ received.

2.☐ received in Application No. (Series Code / Serial Number) _____ .

3.☐ received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

14)☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. & 119(e).

Attachment(s)

15) ☒ Notice of References Cited (PTO-892)

16) ☒ Notice of Draftsperson's Patent Drawing Review (PTO-948)

17) ☐ Information Disclosure Statement(s) (PTO-1449) Paper No(s) _____ .

18) ☐ Interview Summary (PTO-413) Paper No(s). _____

19) ☐ Notice of Informal Patent Application (PTO-152)

20) ☐ Other:

DETAILED ACTION

Drawings

The drawings are objected to as failing to comply with 37 CFR 1.84(p)(5) because they do not include the following reference sign(s) mentioned in the description: integrated cavity (59) on page 12, lines 15 – 16, laser cavity (75) on page 12, lines 25 – 26, and page 13, line 15, cavity (87) on page 14 line 19, particularly simple cavity design (99) on page 15, line 8, and mode-locked laser (105) on page 15, line 20. Correction is required.

Any structural detail that is essential for a proper understanding of the disclosed invention should be shown in the drawing. MPEP § 608.02(d). Correction is required.

Applicant is required to submit a proposed drawing correction in reply to this Office action. However, formal correction of the noted defect can be deferred until the application is allowed by the examiner.

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

Claims 1 – 4, 7, 16 – 19, 22 – 37, 40 – 42, 46 – 47, 50 and 58 are rejected under 35 U.S.C. 102(b) as being anticipated by Fermann et al. (5,627,848).

R garding claims 1 – 4, 7, 16 – 19, 22 – 37, 40 – 42, 46 – 47, 50 and 58 Fermann et al disclose a laser for generating ultra-short optical pulses (Fig. 1, 4 – 8), comprising: a cavity which repeatedly passes light energy along a cavity axis; a length of multi-mode optical fiber (101) doped with a gain medium and positioned along said cavity axis; a pump (103) for exciting said gain medium; a mode locking mechanism (501, abstract and Fig. 8) positioned on said cavity axis; and an optical guide (104) positioned on said cavity axis which confines the light amplified by said multi-mode optical fiber (101) to preferentially the fundamental mode of said multi-mode optical fiber (101). A laser for generating ultra-short optical pulses wherein said mode-locking mechanism comprises a passive mode-locking element (Fig. 1, and Column 3, lines 13 – 26). A laser for generating ultra-short optical pulses wherein said passive mode locking element comprises a saturable absorber (abstract, Column 3, lines 13 – 26, Column 5, lines 61 – 63). A laser for generating ultra-short optical pulses wherein said saturable absorber comprises InGaAsP(Column 5, lines 61 – 63). A laser for generating ultra-short optical pulses wherein said optical guide comprises a single-mode mode-filter (201) fiber on said cavity axis (Column 7, lines 28 – 43 and Column 8, lines 11 – 22). A laser for generating ultra-short optical pulses, additionally comprising a polarization beam splitter (117, abstract, Column 5, lines 10 – 23) for outputting said ultra-short optical pulses from said laser. A laser for generating ultra-short optical pulses, wherein said cavity comprises a pair of reflectors (102, 106) at its opposite ends. A laser for generating ultra-short optical pulses, wherein one of said pair of reflectors (302, 102, 106, Column 7, lines 55 – 67 and Column 8, lines 1 – 22) is partially reflecting and provides the output for said cavity. A laser for generating ultra-short optical pulses, wherein said mode locking mechanism comprises a saturable absorber, and wherein one of said reflectors is formed on a surface of said saturable absorber (Column 7, lines 55 – 67 and Column 8, lines 1 – 59). A laser for generating ultra-short optical pulses, additionally comprising a

linear phase drift compensator on said cavity axis (Fig. 1, 4 – 8). 23. A laser for generating ultra-short optical pulses wherein said linear phase drift compensator comprises a Faraday rotator (113 or 114, Fig. 8, and Column 1, lines 49 – 56 and Column 5, lines 10 – 23). A laser for generating ultra-short optical pulses, wherein said linear phase drift compensator comprises a pair of Faraday rotators(113, 114, Fig. 8, and Column 1, lines 49 – 56 and Column 5, lines 10 – 23). 25. A laser for generating ultra-short optical pulses additionally comprising a linear polarization transformer on said cavity axis (117, abstract, Column 5, lines 10 – 23 and Column 7, lines 55 – 67). A laser for generating ultra-short optical pulses, wherein said linear polarization transformer comprises a wave plate (Fig. 8 Column 5, lines 10 – 23 and Column 6, lines 7 – 16). A laser for generating ultra-short optical pulses, wherein said mode locking mechanism comprises an active mode-locking element (Fig. 6). A laser for generating ultra-short optical pulses, wherein said active mode locking element comprises an optical amplitude modulator (301 or 302 in Fig. 6, Column 7, lines 44 – 54 and Column 8, lines 6 – 22). A laser for generating ultra-short optical pulses, wherein said active mode locking element comprises an optical frequency modulator (301 or 302 in Fig. 6 and Column 7, lines 44 – 54). A laser for generating ultra-short optical pulses, wherein said ultra-short optical pulses preferentially in the fundamental mode of said multi-mode optical fiber have a pulse width below 500 psec (Column 2, lines 51 – 67). A laser for generating ultra-short optical pulses, additionally comprising an environmental stabilizer on said cavity axis to assure that said cavity remains environmentally stable (Column 7, lines 55 – 67 and Column 8, lines 1 – 22). 32. A laser for generating ultra-short optical pulses, wherein said environmental stabilizer comprises a Faraday rotator (113 or 114, Fig. 8, and Column 1, lines 49 – 56 and Column 5, lines 10 – 23). A laser for generating ultra-short optical pulses, wherein said environmental stabilizer comprises a pair of Faraday rotators (113 or 114, Fig. 8, and Column 1, lines 49 – 56 and Column 5, lines 10 – 23).

A laser for generating ultra-short optical pulses, wherein said optical guide comprises an optical fiber doped with an amplifying medium to provide gain guiding (Column 8, lines 1 – 59). A laser for generating ultra-short optical pulses, wherein said amplifying medium is concentrated centrally within a fraction of the core diameter of said optical fiber (Column 4, lines 19 – 40). A laser for generating ultra-short optical pulses, wherein said optical guide comprises a single-mode optical fiber on said cavity axis (Fig. 5, 201 and Column 7, lines 20 – 43). 40. A laser for generating ultra-short optical pulses, wherein said cavity additionally comprises a positive dispersion element (Fig. 5, and Column 7, lines 20 – 43). A laser for generating ultra-short optical pulses, wherein said positive dispersion element comprises a length of single-mode positive dispersion fiber positioned along said cavity axis (Fig. 5, and Column 7, lines 20 – 43). A laser for generating ultra-short optical pulses, additionally comprising an output coupler for limiting the light energy at said single-mode positive dispersion fiber to less than 10% of the peak power in said cavity (Fig. 5, and Column 7, lines 20 – 43). A laser for generating ultra-short optical pulses, wherein said mufti-mode fiber includes a core, and wherein said gain medium in said mufti-mode optical fiber is concentrated centrally within the core of said mufti-mode fiber (Fig. 1 and , 4 – 8). A laser for generating ultra-short optical pulses, wherein said mufti-mode optical fiber is polarization-maintaining (Column 8, lines 32 – 49). A laser for generating ultra-short optical pulses, wherein said cavity additionally comprises a fiber grating (105) written onto said mufti-mode fiber, said grating (105) primarily reflecting the fundamental mode of said mufti-mode fiber. A mode-locked laser for generating high power ultra-short optical pulses (Fig. 1, 4 – 8), comprising: a mufti-mode optical fiber (101) doped with gain material for amplifying optical energy; means for pumping (103) said optical fiber; and means for confining the optical energy amplified by said mufti-mode optical fiber to substantially the fundamental mode of said mufti-mode optical fiber .

Claim R jections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

Claims 8 – 15, 38 – 39, 49 and 49 are rejected under 35 U.S.C. 103(a) as being unpatentable over Fermann et al. (5,627,848).

Fermann et al discloses the claimed invention except for a laser for generating ultra-short optical pulses wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber, a multi-mode fiber is tapered at said fusion splice, the pump is coupled to said multi-mode fiber along said cavity axis, and v-groove on the multi-mode optical fiber for coupling said pump to said multi-mode fiber. It would have been obvious at the time of applicant's invention, of teaching a laser for generating ultra-short optical pulses wherein said single-mode mode-filter fiber is fusion spliced onto one end of said multi-mode optical fiber, a multi-mode fiber is tapered at said fusion splice, the pump is coupled to said multi-mode fiber along said cavity axis, and v-groove on the multi-mode optical fiber for coupling said pump to said multi-mode fiber because are very well known in the art and hence would have been obvious to one of ordinary skill in the art at the time the invention was made to apply these teachings to the claimed apparatus

Allowable Subject Matter

Claims 5 – 6, 20 – 21, and 43 – 45 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims. Claims 5 – 6, 20 – 21, and 43 – 45 have been allowed over the prior art because they fail to teach a laser for generating ultra-short optical pulses, additionally comprising a power limiter for protecting said saturable absorber, power limiter comprises a two photon absorber. A laser for generating ultra-short optical pulses wherein said mode locking mechanism comprises a power limiter for protecting said saturable absorber, and wherein said saturable absorber is formed on a surface of said power limiter opposite said one of said reflectors. A laser for generating ultra-short optical pulses, wherein said frequency converter comprises a frequency doubter. A laser for generating ultra-short optical pulses, wherein said frequency doubter comprises chirped periodically poled $LiNb0_3$.

The following is an examiner's statement of reasons for allowance: claims 51 and 55 has been allowed over the prior art because they fail to teach a method of generating ultra-short pulses, comprising: providing a length of optical fiber doped with a gain medium; repeatedly passing signal light through said length of optical fiber to produce said ultra-short pulses; and providing sufficient stored energy within said gain medium to amplify said pulses to a peak power above 1 KW in combination with the remaining limitation on claims 52 – 54 and 56 – 57.

Claims 52 – 54 and 56 – 57 has been found allowable due to their dependency on claim 51 and 55.

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reason for Allowance"

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Delma R. Flores Ruiz whose telephone number is (703) 308-6238. The examiner can normally be reached on M - F.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Frank G. Font can be reached on (703) 308-4881. The fax phone numbers for the organization where this application or proceeding is assigned are (703) 308-7722 for regular communications and (703) 308-7724 for After Final communications.

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is (703) 308-0956.

Delma R. Flores Ruiz
Examiner
Art Unit 2877

Frank G. Font
Supervisor Patent Examiner
Art Unit 2877

drfr
November 15, 2000

FORM PTO-892 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	SERIAL NO.	GROUP ART UNIT	ATTACHMENT TO PAPER NO.	
NOTICE OF REFERENCES CITED	09/199,728	2877		4
	APPLICANT(S) FERMANN, MARTIN E.			

U.S. PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	NAME	CLASS	SUB-CLASS	FILING DATE
	A	4,835,778	5/1989	Kafka et al.	372	6	
	B	5,450,427	9/1995	Fermann et al.	378	18	
	C	5,187,759	2/1993	DiGiovanni et al.	385	27	
	D	5,627,848	5/1997	Fermann et al.	372	18	
	E	5,689,519	11/1997	Fermann et al	372	18	
	F	5,818,630	10/1998	Fermann et al	359	341	
	G	5,867,304	2/1999	Galvanauskas et al	359	333	
	H	5,880,877	3/1999	Fermann et al	359	341	
	I	6,014,249	1/2000	Fermann et al.	359	341	
	J	6,072,811	6/2000	Fermann et al.	372	11	
	K						

FOREIGN PATENT DOCUMENTS

*		DOCUMENT NO.	DATE	COUNTRY	NAME	CLASS	SUB-CLASS
	L						
	M						
	N						
	O						
	P						
	Q						

OTHER REFERENCES (Including Author, Title, Date, Pertinent Pages, Etc.)

	R	
	S	
	T	
	U	

EXAMINER	DATE	
DELMA R. FLORES RUIZ	October 26, 2000	Form892ccs2106b

* A copy of this reference is not being furnished with this office action.
(See Manual of Patent Examining Procedure, section 707.05(a).)

FIBER OPTICS STANDARD DICTIONARY

THIRD EDITION

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transmission system, interface, optical interface, optical signal, propagation medium, radio, signal, sound signal, telegraph, telephone, transmission system, video, voice.

multimegabit data service: A data service that provides a data signaling rate (DSR) that is over 1 Mb • s^{-1} (Mb/s, megabits per second). *Note:* A fiber optic link has the capability to provide multimegabit data services. *See* **switched multimegabit data service.** *See also* **data signaling rate, fiber optic link, telecommunications service.**

multimeter: A test instrument that (a) is used for measuring voltages, currents, and resistances that may lie within a number of different ranges, (b) has a range selection capability to obtain measurement precision, and (c) must be operated with caution so as not to allow the indicator to go off scale. A measurement should be made starting with the scale that measures the largest unit. *Note:* A lightwave multimeter manufactured by the Hewlett-Packard Company that has two slots for plug-in modules with sensitivities from −70 dBm to −110 dBm and a wavelength range from 450 nm to 1700 nm (0.45 μm to 1.7 μm). *Synonyms* **volt-ohm meter, volt-ohm milliammeter.** *See* **digital multimeter, electronic multimeter, optical multimeter.** *See also* **current, precision, range, scale, voltage.** *Refer to* **Fig. L-8.**

multimode: In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of two or more modes in the wave or (b) the capability of the waveguide to support two or more modes. *See also* **electromagnetic wave, lightwave, mode, optical fiber, propagation, single mode, waveguide.** *Refer to* **Figs. O-1, T-6.**

multimode dispersion: 1. *Synonym* **multimode distortion. 2.** *See* **optical multimode dispersion.**

multimode distortion: In an optical waveguide, such as an optical fiber, a slab dielectric waveguide, or optical integrated circuit (OIC), the distortion that (a) results from differential mode delay, (b) is a result of the spread in time of a pulse because the velocity of propagation is not the same for all the modes in an optical pulse, i.e., optical signal, and (c) is not a result of dispersive mechanisms, i.e., is not a form of dispersion, such as waveguide dispersion, profile dispersion, or material dispersion. *Note 1:* Multimode distortion in multimode step-index optical fibers may be compared to multipath propagation of radio signals. The direct signal is distorted by the arrival of the reflected signals a moment later. In a step-index optical fiber, rays taking more direct paths through the fiber core, i.e., those undergoing fewer reflections at the core-cladding boundary, traverse the length of the fiber sooner than those rays that undergo more reflections, resulting in signal distortion at the end of the fiber. *Note 2:* Multimode distortion limits the bandwidth of a given multimode optical fiber. A typical step index optical fiber with a 50-μm (micron) core would be limited to about 20 MHz (megahertz) for a 1-km (kilometer) length, i.e., a bandwidth • distance factor of 20 MHz • km. *Note 3:* Multimode distortion may be considerably reduced, but not completely eliminated, by the use of a core having a graded refractive index profile. The bandwidth • distance factor of a typical off-the-shelf graded index multimode optical fiber having a 50-μm (micron) core may be over 1 GHz • km (gigahertz • kilometer), with over 10 GHz • km fibers having been produced. *Note 4:* Because of its similarity to dispersion in its effect on optical signals, multimode distortion is sometimes incorrectly referred to as "intermodal dispersion," "modal dispersion," or "multimode dispersion." Such usage is incorrect because multimode distortion is not truly a dispersive effect. Dispersion is a wavelength-dependent phenomenon, particularly because of the spectral width of a pulse, whereas multimode distortion may occur to a single wavelength. *Synonyms* **intermodal distortion, modal distortion, multimode dispersion.** *See also* **bandwidth • distance factor, cladding, coherence area, coherence length, coherence time, core, differential mode delay, distortion, distortion-limited operation, fiber optics, graded refractive index, material dispersion, mode, multimode optical fiber, multipath, optical pulse, optical signal, optical waveguide, profile dispersion, propagation, spectral width, step index optical fiber, waveguide dispersion, wavelength.**

multimode facility: In communications systems, a facility that is capable of handling more than one transmission mode, such as telephone, telegraph, radio, and facsimile transmission. *See also* **facility, facsimile, radio, telegraph, telephone, transmission mode.**

multimode fiber: *Synonym* **multimode optical fiber.**

multimode group delay: *Synonym* **differential mode delay.**

multimode group delay spread: In an electromagnetic wave propagating in a waveguide, such as an optical pulse propagating in an optical fiber, the variation in group delay time, caused by differences in group velocity, among bound propagating modes even at a single frequency. *Note:* The differences in arrival times of the leading and trailing edges of a pulse at the end of the waveguide, as compared to the sending end, is caused by the different propagation delays of the different modes. The modes can be considered as different opti-

cal paths of different optical path lengths. In an optical fiber, it is possible for photons or waves that propagate along the optical fiber axis of the core to arrive at the end sooner than those that follow a helical path through the core, thus causing the pulse duration at the end of the fiber to be increased. If the pulse duration is too great, intersymbol interference, i.e., an overlapping of consecutive pulses, will occur. The duration of the received pulse can be reduced if the refractive index profile of the core is arranged so that light rays taking a helical path along the outer edges of the core propagate through a lower-refractive-index material, hence travel faster in the longer path than axial rays propagating along the optical axis, or in a helical path closer to the axis of the core, in the higher refractive index material, so that they arrive at the end of the fiber at the same time. Actual propagation delay is of little consequence, as long as all rays of a given pulse arrive at the end of the fiber at the same time. Zero-dispersion optical fibers are being made. *Synonym* **differential mode delay.** *See also* **bound mode, core, electromagnetic wave, group delay time, group velocity, intersymbol interference, leading edge, mode, optical fiber, optical fiber axis, optical path length, optical pulse, path, photon, propagation, propagation delay, pulse duration, ray, refractive index profile, trailing edge, wave, zero dispersion, zero-dispersion optical fiber.**

multimode laser: A laser that emits radiation containing two or more modes, i.e., two or more different central wavelengths. *See also* **central wavelength, laser, multiline laser, radiation.**

multimode operation: In analog systems, the use of a common circuit or a single propagation medium for both analog and digital data, such as voice, binary coded data, facsimile, and international Morse code all on one circuit though not necessarily at the same time. *Note:* Simultaneous transmission in more than one transmission mode at the same time can be accomplished using multiplexing techniques. Fiber optic nets, fiber optic links, and fiber optic loops can support multimode operation. *See also* **analog data, circuit, digital data, facsimile, fiber optic link, fiber optic loop, fiber optic net, international Morse code, mode, multiplexing, propagation medium, transmission mode, voice.**

multimode optical fiber: An optical fiber that supports the propagation of more than one bound mode at a given operating wavelength. *Note 1:* A multimode optical fiber may be either a graded index (GI) optical fiber or a step index (SI) optical fiber. *Note 2:* The number of modes that an optical fiber will support depends on the core diameter, the numerical aperture (NA), and the wavelength. *Synonym* **multimode fiber.** *See also* **bound mode, cladding mode, core, core diameter, coupled modes, fiber optics, graded index optical fiber, modal distribution, modal noise, mode, mode scrambler, mode volume, numerical aperture, optical fiber, single-mode optical fiber, step index optical fiber, wavelength.** *Refer to* **Figs. A-6, L-11, R-7.** *Refer to* **Appendix B, Tables 2, 4.**

multimode waveguide: A waveguide that can support more than one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given "multimode" waveguide might support only one mode and therefore could be called a single-mode waveguide if the operating wavelength is long enough, and conversely, a given "single-mode waveguide" might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. *See also* **core, core diameter, mode, numerical aperture, single-mode waveguide, wavelength.**

multinode network: A communications network, such as a fiber optic net, in which users may be interconnected through more than one node. *See also* **fiber optic net, network, node.**

multipaired cable: A paired cable that has two or more pairs of electrical conductors, such as two or more twisted pairs. *See also* **cable, conductor, fiber optic cable, hybrid cable, paired cable, twisted pair.**

multipath: **1.** For lightwaves in dielectric waveguides, pertaining to the different paths taken by the various modes in lightwaves propagating in the waveguide. *Note:* Causes of multipath in optical fibers include refractive index and entrance condition variations. **2.** The propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. *Note 1:* For radio, video, and microwave transmissions, causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings. *Note 2:* Multipath can cause constructive interference, phase shifting, and destructive interference. *Note 3:* In facsimile and television transmission, multipath causes jitter and ghost images. *See also* **antenna, capture effect, constructive interference, destructive interference, dielectric waveguide, entrance condition, facsimile, ghost image, ionosphere, jitter, lightwave, mode, object, phase, phase shift, propagation, Rayleigh fading, reflection, refraction, refractive index, television, waveguide.**

multipath fading: In the propagation of electromagnetic waves, including (a) radio waves in free space and the atmosphere and (b) lightwaves in dielectric waveguides, such as optical fibers, slab dielectric wave-

single harmonic distortion: In a signal, the ratio of (a) the power of a given harmonic, such as the second, third, or fourth harmonic, to (b) the power of the fundamental frequency, i.e., the first harmonic. *Note:* Single harmonic distortion is measured at the output of a device under specified conditions and usually is expressed in dB. *See also* **distortion, frequency, fundamental frequency, harmonic distortion, signal, total harmonic distortion.**

single heterojunction: In a laser diode, a junction that (a) performs two energy level shifts and two refractive index shifts and (b) provides increased confinement of radiation direction, improved control of radiative recombination, and reduced nonradiative (thermal) recombination. *See also* **energy level, junction, laser diode, nonradiative recombination, radiation, radiative recombination.**

single inline package: An integrated circuit package that (a) has a rectangular housing, (b) has one row of pins on a side, and (c) is compatible with standard integrated circuit sockets. *Common abbreviation:* **SIP.** *Note:* An example of a dual inline package (DIP) is a microcircuit package with one row of seven vertical leads that is specially designed for mounting on a printed circuit board. The SIP is used to contain control circuits for controlling fiber optic links and fiber optic nets. *See also* **circuit, dual inline package, fiber optic link, fiber optic net, integrated circuit, large-scale integrated circuit, optical integrated circuit, single inline package switch.**

single lens: A lens composed of only one piece of optical material, such as glass or plastic. *See also* **compound lens, glass, optical glass, optical plastic.**

single mode: **1.** In an electromagnetic wave propagating in a waveguide, such as a lightwave propagating in an optical fiber, pertaining to (a) the existence of one and only one mode in the wave or (b) the capability of the waveguide to support one and only one. **2.** In an electromagnetic wave, such as a lightwave or radio wave, propagating in a waveguide, such as an optical fiber, a hollow or dielectric-filled rectangular metallic waveguide, a slab dielectric waveguide, or an optical integrated circuit (OIC), pertaining to an operating condition in which only one propagation mode, i.e., a beam of only one wavelength, is supported by the waveguide because (a) the wavelength is at the cutoff wavelength, (b) shorter wavelengths could be supported but they are not in the incident wave, i.e., in the wave inserted into the guide, and (c) longer wavelengths cannot be supported even if they are in the incident waves, i.e., they do not fit in the cross section of the guide. *Note 1:* The concept of single mode is also applicable to sound waves in a length of tubing and to vibrations in material media. *Note 2:* An optical fiber designated as a single-mode fiber can support more than one mode by inserting lightwaves of shorter wavelength. Thus, for single-mode operation of a given fiber, the operating wavelength must be specified. *Note 3:* The single mode usually is the lowest order bound mode, consisting of a pair of orthogonally polarized electric and magnetic fields. *See also* **cutoff wavelength, electric field, electromagnetic wave, incident, lightwave, lowest order mode, low-order mode, magnetic field, mode, multimode optical fiber, operating wavelength, optical fiber, optical integrated circuit, orthogonal, polarization, polarized mode, propagation, propagation medium, radio wave, single-mode optical fiber, slab dielectric waveguide, waveguide.** *Refer to* **Figs. O-1, S-20, T-6.**

single-mode fiber: *Synonym* **single-mode optical fiber.**

single-mode launching: The insertion of an electromagnetic wave into a waveguide in such a manner that (a) only one propagation mode is coupled into, and hence transmitted, by the guide, (b) various parameters, such as incidence angle, beam diameter, skew ray angle, and source to waveguide longitudinal displacement are controlled, and (c) propagation of the mode depends on waveguide dimensions, the wavelength of the inserted waves, and refractive indices of the material constituting the guide. *See also* **coupling, electromagnetic wave, incidence angle, mode, parameter, propagation, refractive index, skew ray, transmission, waveguide.**

single-mode optical fiber: An optical fiber in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and core radius. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the core radius must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* In step index optical fibers, single-mode operation occurs when the normalized frequency, V, is less than 2.405. For power law profiles, single-mode operation occurs for a normalized frequency, V, less than approximately $2.405[(g + 2)/g]^{1/2}$, where g is the profile parameter. *Note 4:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonyms* **monomode fiber, monomode optical fiber, single-mode fiber.** *See* **dispersion-unshifted single-mode optical fiber.** *See also* **bound mode, core, core diameter, mode, multimode optical fiber, normalized frequency, numerical aperture, operating

mode, optical fiber, profile parameter, radiation, source, step index optical fiber.** *Refer to* **Figs. E-1, L-11, M-3, R-7, S-9.**

single-mode optical waveguide: An optical waveguide that is capable of supporting the propagation of only one mode at a given wavelength. *Note:* An optical waveguide designed to operate in single mode at a given wavelength may support more than one mode if operated at shorter wavelengths. *See also* **mode, multimode, operating wavelength, optical waveguide, propagation, single mode, single-mode optical fiber, wavelength.**

single-mode waveguide: 1. A waveguide that can support only one mode. *Note:* Because different wavelengths constitute different modes and the number of modes is also dependent on the numerical aperture (NA) and the core diameter, a given multimode waveguide might support only one mode in a given wavelength range and therefore could be called a "single-mode waveguide" if the operating wavelength is long enough, and conversely, a given single-mode waveguide might support several modes and therefore could be called a multimode waveguide if the operating wavelength is short enough. **2.** A waveguide in which only one bound mode, i.e., the lowest order bound mode, can propagate at a given wavelength, numerical aperture, and cross-sectional dimension. *Note 1:* The lowest order bound mode may be a pair of orthogonally polarized electric and magnetic fields. *Note 2:* To support one mode, the cross-sectional dimension must be less than twice the wavelength of the source of radiation and the numerical aperture must be adjusted accordingly. *Note 3:* If appropriate conditions are met, the orthogonal polarizations will not be associated with degenerate modes. *Synonym* **monomode waveguide.** *See also* **bound mode, core, electric field, magnetic field, mode, multimode waveguide, numerical aperture, operating mode, orthogonal, polarization, radiation, range, single-mode optical fiber, source, waveguide, wavelength.**

single-node network: *See* **network topology.**

single optical fiber: An optical fiber that is optically isolated from other optical fibers but may be combined with other optical fibers to form fiber optic cables, aligned bundles, unaligned bundles, and fiber optic faceplates. *See also* **aligned bundle, fiber optic cable, fiber optic faceplate, optical fiber.**

single precedence message: A message in which (a) the same precedence is applicable to all addressees, i.e., to both action addressees and information addressees, and (b) only one precedence designator is needed. *See also* **dual precedence message, message, precedence, precedence designator.**

single sideband: Pertaining to amplitude modulation that (a) primarily is used in carrier telephony and high frequency (HF) radio to increase transmission efficiency, i.e., power efficiency, (b) is used to increase electromagnetic spectrum utilization in terms of the total number of channels available in a given bandwidth, (c) uses only one sideband for transmission while the other sideband and the carrier is suppressed, and (d) although proposed for the uplink and downlink of satellite systems, its use in satellite systems has been limited. *Common abbreviations:* **SS, SSB.** *See also* **amplitude modulation, bandwidth, carrier, channel, downlink, electromagnetic spectrum, satellite communications system, sideband, suppressed carrier, transmission efficiency, uplink.**

single sideband emission: An amplitude-modulated emission with only one sideband. *Common abbreviation:* **SSB emission.** *See also* **amplitude modulation, carrier, double sideband reduced carrier transmission, double sideband suppressed carrier transmission, double sideband transmission, emission, full carrier single sideband emission, reduced carrier single sideband emission, sideband, sideband transmission, suppressed carrier single sideband emission.**

single sideband equipment reference level: The power of one of two equal tones that, when used together to modulate a transmitter, cause it to develop its full rated peak power output. *Common abbreviation:* **SSB equipment reference level.** *See also* **level, peak power output, rated power output, reference, reference circuit, reference level, sideband transmission, transmitter.**

single sideband noise power ratio: The ratio of (a) the output power, measured with a notch in, to (b) the output power, measured with the notch out. *Note 1:* Measurements are made in which (a) notched noise is used, (b) power is in the notch bandwidth, and (c) power is measured at the output of the device for which the single sideband (SSB) noise power ratio is being determined. *Note 2:* The input power must be sufficient to maintain a constant total system mean noise power output. *See also* **noise, notch, notched noise.**

single sideband suppressed carrier (SSB-SC) transmission: Single sideband transmission in which (a) the carrier is suppressed and (b) the carrier power level is suppressed so that it is insufficient for signal demodulation. *Common abbreviation:* **SSB-SC transmission.** *See also* **carrier, demodulation, power level, single sideband transmission.**

single sideband transmission: Sideband transmission in which (a) only one sideband is transmitted and (b) the